PROBLEMS

1. (a) $K_{sp} = [Co^{3+}]^2[S^{2-}]^3$ (b) $K_{sp} = [Pb^{2+}][Cl^-]^2$

   (c) $K_{sp} = [Zn^{2+}]^2[P_2O_7^{4-}]$ (d) $K_{sp} = [Sc^{3+}][OH^-]^3$

3. (a) $Hg_2Cl_2(s) \rightleftharpoons Hg_2^{2+}(aq) + 2\,Cl^-(aq)$ (b) $PbCrO_4(s) \rightleftharpoons Pb^{2+}(aq) + CrO_4^{2-}(aq)$

   (c) $MnO_2(s) \rightleftharpoons Mn^{4+}(aq) + 2\,O^{2-}(aq)$ (d) $Al_2S_3(s) \rightleftharpoons 2\,Al^{3+}(aq) + 3\,S^{2-}(aq)$

5. (a) $[OH^-]^2 = \dfrac{2.5 \times 10^{-14}}{1.5 \times 10^{-6}} = 1.67 \times 10^{-8}$; $[OH^-] = 1.3 \times 10^{-4}\ M$

   (b) $[Cu^{2+}]^3 = \dfrac{7.6 \times 10^{-36}}{(2.4 \times 10^{-4})^2} = 1.3 \times 10^{-28}$; $[Cu^{2+}] = 5.1 \times 10^{-10}\ M$

   (c) $[Zn^{2+}] = \dfrac{2.7 \times 10^{-8}}{8.8 \times 10^{-3}} = 3.1 \times 10^{-6}\ M$

7. (a) $[Pb^{2+}] = \dfrac{K_{sp}\ PbBr_2}{[Br^-]^2} = \dfrac{6.6 \times 10^{-6}}{(0.019)^2} = 0.018\ M$

   (b) $[Hg_2^{2+}] = \dfrac{K_{sp}\ Hg_2Br_2}{(0.019)^2} = \dfrac{6 \times 10^{-23}}{(0.019)^2} = 2 \times 10^{-19}\ M$

   (c) $[Ag^+] = \dfrac{5 \times 10^{-13}}{0.019} = 3 \times 10^{-11}\ M$

9. (a) $1 \times 10^{-10} = [Co^{2+}][CO_3^{2-}]$; $[Co^{2+}] = [CO_3^{2-}] = 1 \times 10^{-5}\ M$

   (b) $2 \times 10^{-19} = [La^{3+}][F^-]^3$; $[La^{3+}] = \dfrac{2 \times 10^{-19}}{(7 \times 10^{-6})^3} = 6 \times 10^{-4}\ M$

   (c) $6 \times 10^{-39} = [Ba^{2+}]^3[PO_4^{3-}]^2$; $[PO_4^{3-}]^2 = \dfrac{6 \times 10^{-39}}{(4.2 \times 10^{-8})^3}$; $[PO_4^{3-}] = 9 \times 10^{-9}\ M$

11. (a) $[Ba^{2+}] = \dfrac{K_{sp}\ BaF_2}{[F^-]^2} = \dfrac{1.8 \times 10^{-7}}{(0.025)^2} = 2.9 \times 10^{-4}\ M$

    (b) $[F^-]^2 = \dfrac{1.8 \times 10^{-7}}{0.0045}$; $[F^-] = 6.3 \times 10^{-3}\ M$

    $\%\ F^-\ \text{left} = \dfrac{6.3 \times 10^{-3}}{2.5 \times 10^{-2}} \times 100\% = 25\%$; F^- precipitated = 75%

13. $[Ca^{2+}] = \dfrac{3.0 \times 10^{-3}\ \text{g/L}}{40.08\ \text{g/mol}} = 7.5 \times 10^{-5}\ M$

$[SO_4^{2-}] = \dfrac{5.0 \times 10^{-4}\ \text{g/L}}{142.1\ \text{g/mol}} = 3.5 \times 10^{-6}\ M$

$Q = (7.5 \times 10^{-5})(3.5 \times 10^{-6}) = 2.6 \times 10^{-10} < 7.1 \times 10^{-5}$; no

$[SO_4^{2-}] = \dfrac{7.1 \times 10^{-5}}{7.5 \times 10^{-5}} = 0.95\ M$

15. $Hg_2^{2+}(aq) + 2\,Cl^-(aq) \rightleftharpoons Hg_2Cl_2(s)$ $\qquad K_{sp} = 1 \times 10^{-18}$

(a) mol Hg_2^{2+} = mol Hg_2Cl_2 = (0.01300 L)(0.0021 mol/L) = 2.7×10^{-5}

$[Hg_2^{2+}] = \dfrac{2.7 \times 10^{-5}\ \text{mol}}{0.013\ \text{L} + 0.025\ \text{L}} = 7.4 \times 10^{-4}\ M$

mol Cl^- = mol HCl = (0.0250 L)(0.015 mol/L) = 3.8×10^{-4}

$[Cl^-] = \dfrac{3.8 \times 10^{-4}\ \text{mol}}{0.013\ \text{L} + 0.025\ \text{L}} = 9.9 \times 10^{-3}\ M$

$Q = = [Hg_2^{2+}][Cl^-]^2 = (7.4 \times 10^{-4})(9.9 \times 10^{-3})^2 = 7.2 \times 10^{-8} > 1 \times 10^{-18}$; yes

(b) Before reaction, there are 3.8×10^{-4} mol Cl^- and 2.7×10^{-5} mol Hg_2^{2+}.

2.7×10^{-5} mol Hg_2^{2+} will react with $2(2.7 \times 10^{-5}) = 5.4 \times 10^{-5}$ mol Cl^-.

Hg_2^{2+} is limiting and used up. mol Cl^- left = $3.8 \times 10^{-4} - 5.4 \times 10^{-5} = 3.3 \times 10^{-4}$

$[Cl^-] = \dfrac{3.3 \times 10^{-4}\ \text{mol}}{0.013\ \text{L} + 0.025\ \text{L}} = 8.7 \times 10^{-3}\ M$

mol NO_3^- = 2(mol $Hg_2(NO_3)_2$) = $2(2.7 \times 10^{-5}) = 5.4 \times 10^{-5}$

$[NO_3^-] = \dfrac{5.4 \times 10^{-5}\ \text{mol}}{0.013\ \text{L} + 0.025\ \text{L}} = 1.4 \times 10^{-3}\ M$

$[Hg_2^{2+}]$ after equilibrium with the precipitate is established:

$1 \times 10^{-18} = [Hg_2^{2+}][Cl^-]^2 = [Hg_2^{2+}][8.7 \times 10^{-3}]^2$; $[Hg_2^{2+}] = 1 \times 10^{-14}\ M$

17. let s = molar solubility of the solid

(a) $[PbCl_2] = s$; $[Pb^{2+}] = s$; $[Cl^-] = 2s$

$1.7 \times 10^{-5} = [Pb^{2+}][Cl^-]^2 = (s)(2s)^2$; $s = 0.016\ M = [PbCl_2]$

(b) $[Ca_3(PO_4)_2] = s$; $[Ca^{2+}] = 3s$; $[PO_4^{3-}] = 2s$

$1 \times 10^{-33} = (3s)^3(2s)^2$; $s = 1 \times 10^{-7}\ M = [Ca_3(PO_4)_2]$

(c) $[Ag_2CO_3] = s$; $[Ag^+] = 2s$; $[CO_3^{2-}] = s$

$8 \times 10^{-12} = (2s)^2(s)$; $s = 1 \times 10^{-4}\ M = [Ag_2CO_3]$

19. (a) $K_{sp} = [Zn^{2+}][CO_3^{2-}]$; $[Zn^{2+}] = [CO_3^{2-}] = [ZnCO_3] = 1.21 \times 10^{-5}$

$K_{sp} = (1.21 \times 10^{-5})(1.21 \times 10^{-5}) = 1.46 \times 10^{-10}$

(b) $K_{sp} = [Ag^+]^2[SO_4^{2-}]$; $[SO_4^{2-}] = [Ag_2SO_4] = 0.014\ M$; $[Ag^+] = 2[SO_4^{2-}] = 0.028\ M$

$K_{sp} = (0.028)^2(0.014) = 1.1 \times 10^{-5}$

(c) $K_{sp} = [Sr^{2+}]^3[PO_4^{3-}]^2$; $[Sr^{2+}] = 3[Sr_3(PO_4)_2] = 3(2.5 \times 10^{-7}\ M) = 7.5 \times 10^{-7}\ M$

$[PO_4^{3-}] = 2[Sr_3(PO_4)_2] = 2(2.5 \times 10^{-7}\ M) = 5.0 \times 10^{-7}\ M$

$K_{sp} = (7.5 \times 10^{-7})^3(5.0 \times 10^{-7})^2 = 1.1 \times 10^{-31}$

21. $AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$ $\quad K_{sp} = 1.8 \times 10^{-10}$

Let s = molar solubility of AgCl = [AgCl]; $\quad s = [Ag^+] = [Cl^-]$

(a) $1.8 \times 10^{-10} = (s)(s)$; $\quad s = 1.3 \times 10^{-5}\ M = [AgCl]$; $\quad (1.3 \times 10^{-5}$ mol/L)(143.4 g/mol) = 0.0019 g/L

(b) $[Cl^-]$ from AgCl = s; $\quad [Cl^-]$ from $BaCl_2 = 2[BaCl_2] = 2(0.025) = 0.050\ M$

$[Cl^-] = s + 0.050$; $\quad$ Assume $s << 0.050$; $\quad [Cl^-] = 0.050\ M$

$1.8 \times 10^{-10} = (s)(0.050)$; $\quad s = 3.6 \times 10^{-9}\ M$; $\quad (3.6 \times 10^{-9}$ mol/L)(143.4 g/mol) = 5.2×10^{-7} g/L

(c) $[Ag^+]$ from AgCl = s; $\quad [Ag^+]$ from $AgNO_3 = [AgNO_3] = 0.17\ M$

$[Ag^+] = s + 0.17$; $\quad$ Assume $s << 0.17$; $\quad [Ag^+] = 0.17\ M$

$1.8 \times 10^{-10} = (s)(0.17)$; $\quad s = 1.1 \times 10^{-9}\ M$; $\quad (1.1 \times 10^{-9}$ mol/L)(143.4 g/mol) = 1.5×10^{-7} g/L

23. 25×10^{-3} g $Pb(N_3)_2 \times \dfrac{1 \text{ mol}}{291.3 \text{ g}} = 8.6 \times 10^{-5}$ mol; $\quad [Pb(N_3)_2] = \dfrac{8.6 \times 10^{-5} \text{ mol}}{0.100 \text{ L}} = 8.6 \times 10^{-4}$ mol/L

$[Pb^{2+}] = 8.6 \times 10^{-4}\ M$; $\quad [N_3^-] = 2(8.6 \times 10^{-4}\ M) = 0.0017\ M$

$K_{sp} = (8.6 \times 10^{-4})(0.0017)^2 = 2.5 \times 10^{-9}$

25. At 25°C, $K_{sp} = 1.7 \times 10^{-5}$. $\quad$ Let s = molar solubility of $PbCl_2$; $\quad [PbCl_2] = [Pb^{2+}] = s$; $[Cl^-] = 2s$

$1.7 \times 10^{-5} = (s)(2s)^2$; $\quad s = 0.016$ mol/L; $\quad$ (0.016 mol/L)(278.1 g/mol) = 4.50 g will dissolve in 1 L.

Since only 1.0 g $PbCl_2$ is added, none will crystallize out.

27. $Fe(OH)_2(s) \rightleftharpoons Fe^{2+}(aq) + 2\,OH^-(aq)$ $\quad K_{sp} = 5 \times 10^{-17}$

$[Fe(OH)_2] = [Fe^{2+}] = s$ = molar solubility of $Fe(OH)_2$

(a) $5 \times 10^{-17} = (s)(1 \times 10^{-10})$; $\quad s = 5 \times 10^{-7}$ mol/L

$(5 \times 10^{-7}$ mol/L)(89.87 g/mol)(0.100 L) = 4×10^{-6} g

(b) $5 \times 10^{-17} = (s)(1 \times 10^{-7})$; $s = 5 \times 10^{-10}$ mol/L

$(5 \times 10^{-10}$ mol/L)(89.87 g/mol)(0.100 L) $= 4 \times 10^{-9}$ g

(c) $5 \times 10^{-17} = (s)(1 \times 10^{-4})$; $s = 5 \times 10^{-13}$ mol/L

$(5 \times 10^{-13}$ mol/L)(89.87 g/mol)(0.100 L) $= 4 \times 10^{-12}$ g

29. $[Ba^{2+}] = [Ba(OH)_2] = \dfrac{2.37 \text{ g } Ba(OH)_2}{0.100 \text{ L}} \times \dfrac{1 \text{ mol}}{171.3 \text{ g}} = 0.138\ M$

pH = 13.28; pOH = 0.72; $[OH^-] = 0.19\ M$

$K_{sp} = [Ba^{2+}][OH^-]^2 = (0.138)(0.19)^2 = 5.0 \times 10^{-3}$

31. (a) $[Pb^{2+}]$ to precipitate $PbSO_4 = 1.8 \times 10^{-8}/0.035 = 5.1 \times 10^{-7}\ M$

$[Pb^{2+}]$ to precipitate $PbCrO_4 = 2 \times 10^{-14}/0.035 = 5.7 \times 10^{-13}\ M$

$PbCrO_4$ precipitates first.

(b) $5.7 \times 10^{-13}\ M$

33. (a) mol Al^{3+} = (0.40 mol/L)(0.065 L) = 0.026 ; $[Al^{3+}] = \dfrac{0.026 \text{ mol}}{0.065 \text{ L} + 0.125 \text{ L}} = 0.14\ M$

mol Fe^{2+} = (0.17 mol/L)(0.125 L) = 0.021 ; $[Fe^{2+}] = \dfrac{0.021 \text{ mol}}{0.065 \text{ L} + 0.125 \text{ L}} = 0.11\ M$

OH^- needed to precipitate Al^{3+} as $Al(OH)_3$: $2 \times 10^{-31} = (0.14)[OH^-]^3$; $[OH^-] = 1 \times 10^{-10}$

OH^- needed to precipitate Fe^{2+} as $Fe(OH)_2$: $5 \times 10^{-17} = (0.11)[OH^-]^2$; $[OH^-] = 2 \times 10^{-8}$

$Al(OH)_3$ will precipitate first

(b) $\approx 1 \times 10^{-10}\ M$

35. Total volume of solution = 0.125 L + 0.225 L + 0.025 L = 0.375 L

mol Au^+ = (0.100 mol/L)(0.125 L) = 0.0125 ; $[Au^+] = \dfrac{0.0125 \text{ mol}}{0.375 \text{ L}} = 0.0333\ M$

mol Ag^+ = (0.049 mol/L)(0.225 L) = 0.011 ; $[Ag^+] = \dfrac{0.011 \text{ mol}}{0.375 \text{ L}} = 0.029\ M$

mol Cl^- = (0.0100 mol/L)(0.025 L) = 2.5×10^{-4} ; $[Cl^-] = \dfrac{2.5 \times 10^{-4} \text{ mol}}{0.375 \text{ L}} = 6.7 \times 10^{-4}\ M$

Q for AuCl = $(0.0333)(6.7 \times 10^{-4}) = 2.2 \times 10^{-5} > 2.0 \times 10^{-13}$

Q for AgCl = $(0.029)(6.7 \times 10^{-4}) = 2.0 \times 10^{-5} > 1.8 \times 10^{-10}$

Theoretically, both AuCl and AgCl should precipitate, but mol Cl^- $(2.5 \times 10^{-4}) \ll$ mol Au^+ (0.0125). Since AuCl will precipitate first (smaller K_{sp}), it will consume all the chloride. AgCl will not precipiate.

37. (a) $Cu_2S(s) + 2\,H^+(aq) \rightarrow 2\,Cu^+(aq) + H_2S(g)$

(b) no reaction

(c) $SrCO_3(s) + 2\,H^+(aq) \rightarrow Sr^{2+}(aq) + H_2CO_3(aq)$

(d) $Cu(NH_3)_4^{2+}(aq) + 4\,H^+(aq) \rightarrow Cu^{2+}(aq) + 4\,NH_4^+(aq)$

(e) $Ca(OH)_2(s) + 2\,H^+(aq) \rightarrow Ca^{2+}(aq) + 2\,H_2O$

39. (a) $AgCl(s) + 2\,NH_3(aq) \rightarrow Ag(NH_3)_2^+(aq) + Cl^-(aq)$

(b) $Al^{3+}(aq) + 3\,NH_3(aq) + 3\,H_2O \rightarrow Al(OH)_3(s) + 3\,NH_4^+(aq)$

(c) $Cu^{2+}(aq) + 4\,NH_3(aq) \rightarrow Cu(NH_3)_4^{2+}(aq)$

41. (a) $Sb^{3+}(aq) + 3\,OH^-(aq) \rightarrow Sb(OH)_3(s)$

(b) $Sb(OH)_3(s) + OH^-(aq) \rightarrow Sb(OH)_4^-(aq)$

(c) $Sb^{3+}(aq) + 4\,OH^-(aq) \rightarrow Sb(OH)_4^-(aq)$

43. $CuCl(s) \rightleftharpoons Cu^+(aq) + Cl^-(aq) \qquad K_1 = K_{sp}\ CuCl$

$Cu^+(aq) + 2\,CN^-(aq) \rightleftharpoons Cu(CN)_2^-(aq) \qquad K_2 = K_f\ Cu(CN)_2^-$

$CuCl(s) + 2\,CN^-(aq) \rightleftharpoons Cu(CN)_2^-(aq) + Cl^-(aq)$

$K = (K_{sp}\ CuCl)(K_f\ Cu(CN)_2^-) = (1.9 \times 10^{-7})(1.0 \times 10^{16}) = 1.9 \times 10^9$

45. (a) $Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2\,OH^-(aq)$

$Zn^{2+}(aq) + 2\,CN^-(aq) \rightleftharpoons Zn(CN)_2(s)$

$Zn(OH)_2(s) + 2\,CN^-(aq) \rightleftharpoons Zn(CN)_2(s) + 2\,OH^-(aq)$

$$K = \frac{K_{sp}\ Zn(OH)_2}{K_{sp}\ Zn(CN)_2} = \frac{4 \times 10^{-17}}{8.0 \times 10^{-12}} = 5 \times 10^{-6}$$

(b) no; K (5×10^{-6}) is too small

47. (a) $Al(OH)_3(s) + OH^-(aq) \rightleftharpoons Al(OH)_4^-(aq)$

(b) $Al(OH)_3(s) \rightleftharpoons Al^{3+}(aq) + 3\,OH^-(aq)$

$Al^{3+}(aq) + 4\,OH^-(aq) \rightleftharpoons Al(OH)_4^-(aq)$

$Al(OH)_3(s) + OH^-(aq) \rightleftharpoons Al(OH)_4^-(aq)$

$K = (K_{sp}\ Al(OH)_3)(K_f\ Al(OH)_4^-) = (2 \times 10^{-31})(1 \times 10^{33}) = 2 \times 10^2$

(c) $2 \times 10^2 = \dfrac{[Al(OH)_4^-]}{1 \times 10^{-2}}$; $[Al(OH)_4^-] \approx 2\ M$

49. $AuCl(s) + 2\,CN^-(aq) \rightleftharpoons Au(CN)_2^-(aq) + Cl^-(aq)$

$K = (K_{sp}\ AuCl)(K_f\ Au(CN)_2^-) = (2.0 \times 10^{-13})(2 \times 10^{38}) = 4 \times 10^{25}$

$4 \times 10^{25} = \dfrac{[Au(CN)_2^-][Cl^-]}{[CN^-]^2} = \dfrac{s^2}{0.010}$; $s = 6 \times 10^{11}\ M$ (completely soluble)

51. (a) $CdC_2O_4(s) \rightleftharpoons Cd^{2+}(aq) + C_2O_4^{2-}(aq)$

$Cd^{2+}(aq) + 4\,NH_3(aq) \rightleftharpoons Cd(NH_3)_4^{2+}(aq)$

$CdC_2O_4(s) + 4\,NH_3(aq) \rightleftharpoons Cd(NH_3)_4^{2+}(aq) + C_2O_4^{2-}(aq)$

$K = (K_{sp}\ CdC_2O_4)(K_f\ Cd(NH_3)_4^{2+}) = (1.5 \times 10^{-8})(2.8 \times 10^7) = 0.42$

(b) $[C_2O_4^{2-}] = [CdC_2O_4] = \dfrac{2.00\text{ g}}{1.00\text{ L}} \times \dfrac{1\text{ mol}}{200.4\text{ g}} = 0.0100\ M$; $[Cd(NH_3)_4^{2+}] = [C_2O_4^{2-}]$

$0.42 = \dfrac{[Cd(NH_3)_4^{2+}][C_2O_4^{2-}]}{[NH_3]^4} = \dfrac{(0.0100)^2}{[NH_3]^4}$; $[NH_3] = 0.12\ M$

53. mol Ca^{2+} in blood sample $= \dfrac{0.10 \times 10^{-3}\text{ g}}{1\text{ mL}} \times 250.0\text{ mL} \times \dfrac{1\text{ mol}}{40.08\text{ g}} = 6.2 \times 10^{-4}$

mol $C_2O_4^{2-}$ in precipitating solution = (0.160 mol/L)(0.2500 L) = 0.0400

$Ca^{2+}(aq) + C_2O_4^{2-}(aq) \rightarrow CaC_2O_4(s)$

Ca^{2+} is limiting and used up.

mol $C_2O_4^{2-} = 0.0400 - 6.2 \times 10^{-4} = 0.0394$; $[C_2O_4^{2-}] = \dfrac{0.0394\text{ mol}}{0.250\text{ L} + 0.250\text{ L}} = 0.0788\ M$

$4 \times 10^{-9} = [Ca^{2+}][0.0788]$; $[Ca^{2+}] = 5 \times 10^{-8}\ M$

55. $[F^-] = \dfrac{2.0\text{ g}}{10^3\text{ L water}} \times \dfrac{1\text{ mol}}{19.0\text{ g}} = 1.1 \times 10^{-4}\ M$

$Q = (3.5 \times 10^{-4})(1.1 \times 10^{-4})^2 = 4.2 \times 10^{-12} < K_{sp}\ CaF_2\ (1.5 \times 10^{-10})$; no

57. (a) $Fe^{2+}(aq) + 2\,OH^-(aq) \rightarrow Fe(OH)_2(s)$

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

(b) mol Fe^{2+} = mol SO_4^{2-} = mol $FeSO_4$ = (0.0250 L)(0.500 mol/L) = 0.0125

mol $Ba(OH)_2$ = mol Ba^{2+} = (0.0350 L)(0.332 mol/L) = 0.0116 ; mol OH^- = 2(mol Ba^{2+}) = 0.0232

For $Fe(OH)_2$ precipitation: OH^- is limiting and 0.0116 mol $Fe(OH)_2$ are formed.

mass $Fe(OH)_2$ = (0.0116 mol)(89.87 g/mol) = 1.04 g

For $BaSO_4$ precipitation: Ba^{2+} is limiting and 0.0116 mol $BaSO_4$ are formed.

mass $BaSO_4$ = (0.0116 mol)(233.4 g/mol) = 2.71 g

(c) mol SO_4^{2-} unreacted = 0.0125 – 0.0116 = 9.00×10^{-4} ; $[SO_4^{2-}] = \dfrac{9.00 \times 10^{-4} \text{ mol}}{0.0350 \text{ L} + 0.0250 \text{ L}} = 0.015\ M$

$1.1 \times 10^{-10} = [Ba^{2+}][SO_4^{2-}] = [Ba^{2+}](0.015)$; $[Ba^{2+}] = 7.3 \times 10^{-9}\ M$

$[Fe^{2+}] = [SO_4^{2-}] = 0.015\ M$

$5 \times 10^{-17} = [Fe^{2+}][OH^-]^2 = (0.015)[OH^-]^2$; $[OH^-] = 6 \times 10^{-8}\ M$

59. (a)

$CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq)$	$K_{sp} = 4.9 \times 10^{-9}$
$H^+(aq) + CO_3^{2-}(aq) \rightleftharpoons HCO_3^-(aq)$	$1/K_a = 1/4.7 \times 10^{-11}$
$CaCO_3(s) + H^+(aq) \rightleftharpoons Ca^{2+}(aq) + HCO_3^-(aq)$	$K = 1.0 \times 10^2$

(b) Let s = $[CaCO_3]$; $[CaCO_3] = [Ca^{2+}] = [CO_3^{2-}] = s$

$4.9 \times 10^{-9} = (s)(s)$; $s = 7 \times 10^{-5}\ M$

(c) $1.0 \times 10^2 = \dfrac{[Ca^{2+}][HCO_3^-]}{[H^+]}$; $[CaCO_3] = [Ca^{2+}] = [HCO_3^-] = s$

$1.0 \times 10^2 = \dfrac{(s)(s)}{1.0 \times 10^{-4}}$; $s = 0.10\ M$

61. 7 □ , 7 ◯ in solution

63. 4 □ , 8 ◯ in solution, 2 ◯□◯ at bottom

65. (a)

JQ	$s^2 = 1 \times 10^{-10}$	$s = 1 \times 10^{-5}$	
K_2R	$4s^3 = 1 \times 10^{-10}$	$s = 3 \times 10^{-4}$	
L_2S_3	$108s^5 = 1 \times 10^{-10}$	$s = 4 \times 10^{-3}$	greatest molar solubility
MT_2	$4s^3 = 1 \times 10^{-10}$	$s = 3 \times 10^{-4}$	
NU_3	$27s^4 = 1 \times 10^{-10}$	$s = 1 \times 10^{-3}$	

(b) can't tell without molar mass

(c) no; don't know molar mass

67. (a) T (b) T (c) F (d) T (e) T

69. $Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$ $K_1 = 6 \times 10^{-12}$

$2NH_4^+(aq) \rightleftharpoons 2H^+(aq) + 2NH_3(aq)$ $(K_2)^2 = (5.6 \times 10^{-10})^2$

$2H^+(aq) + 2OH^-(aq) \rightleftharpoons 2H_2O$ $K_3 = (1/K_W)^2 = (1.0/1 \times 10^{-14})^2$

$$K = K_1K_2K_3 = \frac{(6 \times 10^{-12})(5.6 \times 10^{-10})^2}{(1.0 \times 10^{-14})^2} = 2 \times 10^{-2}$$

$$2 \times 10^{-2} = \frac{(s)(2s)^2}{[NH_4^+]^2} = \frac{(s)(2s)^2}{(0.2)^2} \qquad s = 0.06\ M$$

In water: $4s^3 = 6 \times 10^{-12}$; $s = 1 \times 10^{-4}\ M$

70. $$K = \frac{K_{sp}\ CaF_2}{(K_a\ HF)^2} = 3.2 \times 10^{-4}\ ; \qquad [H^+] = 1.9 \times 10^{-4} \times \frac{0.30}{0.20} = 2.8 \times 10^{-4}$$

$$3.2 \times 10^{-4} = \frac{4s^3}{(2.8 \times 10^{-4})^2}\ ; \qquad s = 1.8 \times 10^{-4}\ M$$

71. $$[Ag^+] = \frac{K_{sp}\ AgCl}{[Cl^-]} = \frac{1.8 \times 10^{-10}}{0.020} = 9.0 \times 10^{-9}\ M$$

$$[I^-] = \frac{K_{sp}\ AgI}{[Ag^+]} = \frac{1 \times 10^{-16}}{9.0 \times 10^{-9}} = 1 \times 10^{-8}\ M$$

72. (a) $$[OH^-]^2 = \frac{6 \times 10^{-12}}{5.6 \times 10^{-2}}\ ; \qquad [OH^-] = 1 \times 10^{-5}\ M$$

(b) $Al(OH)_3$: $Q = (4 \times 10^{-7})(1 \times 10^{-5})^3 = 4 \times 10^{-22} > K_{sp}$

$Fe(OH)_3$: $Q = (2 \times 10^{-7})(1 \times 10^{-5})^3 = 2 \times 10^{-22} > K_{sp}$

$Al(OH)_3$ and $Fe(OH)_3$ precipitate.

(c) $[OH^-]^2 = (6 \times 10^{-12})/(2.8 \times 10^{-2})$; $[OH^-] \approx 1 \times 10^{-5}\ M$

$[Al^{3+}] = (2 \times 10^{-31})/(1 \times 10^{-15}) = 2 \times 10^{-16}\ M$; $[Fe^{3+}] = 3 \times 10^{-24}\ M$

virtually all

(d) 0.028 mol $Mg(OH)_2$ + (4×10^{-7} mol $Al(OH)_3$) + (2×10^{-7} mol $Fe(OH)_3$)

(0.028 mol)(58.32 g/mol) = 1.6 g

73. (a) $K = \dfrac{K_f\ Zn(OH)_4^{2-}}{K_f\ Zn(NH_3)_4^{2+}} = \dfrac{3 \times 10^{14}}{3.6 \times 10^{8}} = 8 \times 10^{5}$

(b) In 1.0 M NH_3: $[OH^-] = 4.2 \times 10^{-3}\ M$

$$\frac{Zn(OH)_4^{2-}}{Zn(NH_3)_4^{2+}} = \frac{(8 \times 10^{5})(4.2 \times 10^{-3})^4}{(1.0)^4} = 2.6 \times 10^{-4}\ ; \qquad \frac{Zn(NH_3)_4^{2+}}{Zn(OH)_4^{2-}} = 4 \times 10^{3}$$

74. $Ag(NH_3)_2^+(aq) \rightleftharpoons Ag^+(aq) + 2\,NH_3(aq)$ $\qquad K = 1/K_f$

$2\,NH_3(aq) + 2\,H^+(aq) \rightleftharpoons 2\,NH_4^+(aq)$ $\qquad K = 1/(K_a)^2$

$Ag^+(aq) + Cl^-(aq) \rightleftharpoons AgCl(s)$ $\qquad K = 1/K_{sp}$

$$K = \frac{1}{K_f\,(K_a)^2\,K_{sp}} = 1.0 \times 10^{21}$$